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First record and evidence of an established population of the North American mud crab *Dyspanopeus sayi* (Brachyura: Heterotremata: Panopeidae) in the western Mediterranean

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SUMMARY: The panopeid crab *Dyspanopeus sayi* (Smith, 1869) is reported here from the Ebro Delta (Mediterranean coast of the Iberian Peninsula). Originally endemic to the Atlantic coast of North America, *D. sayi* was involuntarily introduced into Britain, France and the Netherlands, and into the Adriatic and Black Sea within the last thirty years. Here we provide the first record of this species from the western Mediterranean Sea. Occurrences of ovigerous females at different localities of the delta and in different years provide evidence that the population is well established. Mitochondrial DNA confirms the identity of the species and indicates that the introduced population consists of at least three female lineages. The first zoeal stage of *D. sayi* was obtained in the laboratory from an ovigerous female captured in August 2010 with embryos in an advanced stage of development. The morphology of the zoea I is described here in detail and is similar to the one previously reported for native populations.

Keywords: *Dyspanopeus sayi*, alien species, Mediterranean, Ebro Delta, mtDNA sequences, zoea.

RESUMEN: PRIMERA CITA Y EVIDENCIA DE UNA POBLACIÓN ESTABLECIDA DEL CANGREJO AMERICANO *DYSPANOPEUS SAYI* (BRACHYURA: HETEROTREMATA: PANOPEIDAE) EN EL MEDITERRÁNEO OCCIDENTAL. – Se informa de la presencia del cangrejo panopeido *Dyspanopeus sayi* (Smith, 1869) en el Delta del Ebro (costa mediterránea de la Península Ibérica). Originalmente endémica de la costa atlántica de América del Norte, *D. sayi* se introdujo en Gran Bretaña, Francia, los Países Bajos, en el Adriático y el Mar Negro en los últimos treinta años. En el presente trabajo se presenta el primer registro de esta especie en el Mediterráneo occidental. La presencia de hembras ovígeras en diferentes localidades del Delta del Ebro y en diferentes años evidencia que la población está bien establecida. El ADN mitocondrial confirma la identidad de la especie e indica que la población introducida consiste de por lo menos tres linajes de hembras. El primer estadio de zoea de *D. sayi* se obtuvo en el laboratorio a partir de una hembra ovígera capturada en agosto de 2010, con embriones en una etapa avanzada de desarrollo. La morfología de la zoea I se describe en detalle, siendo similar a descripciones anteriores de poblaciones oriundas.

Palabras clave: *Dyspanopeus sayi*, especies invasoras, Mediterráneo, Delta del Ebro, secuencias de mtADN, zoea.

INTRODUCTION

Non-indigenous species represent potentially significant stressors in marine and estuarine communities (Ruiz *et al.* 1999). In addition to environmental concerns, alien species can also create serious economic and health impacts (Pimentel *et al*. 2005). The Mediterranean Sea has been exceptionally susceptible to biological invasions, especially after the opening of the Suez Canal and the connection to the Indo-Pacific via the Red Sea (Galil *et al*. 2002). Among others, two species of Panopeidae have established large populations in estuarine habitats of the Mediterranean and Black Sea, namely *Rhithropanopeus harrisii* (Gould, 1841) (see Projecto-Garcia *et al*. 2010) and *Dyspanopeus sayi* (Smith, 1869).

Say's mud crab *Dyspanopeus sayi* is endemic to the northwestern Atlantic Ocean from Canada to Florida (Nizinski 2003). The species is most closely related to the second species and type of the genus, *D. texanus* (Stimpson, 1859), from the Gulf of Mexico. *Dyspanopeus* Martin and Abele, 1986 is the sister taxon to the genus *Neopanope* A. Milne-Edwards, 1880 (see Schubart *et al*. 2000), to which *D. sayi* and *D. texanus* used to belong before Martin and Abele (1986) placed them in their own genus. *D. sayi* is a euryhaline and eurythermic species inhabiting estuaries and shallow coastal marine waters from the intertidal to 46 m depth (Williams 1984). Within its native range, the mud crab is a common predator of shallow water bivalves (Strieb *et al*. 1995, Newell *et al*. 2007). Its larval development consists of four zoeal stages and one megalopa (Hyman 1925, Chamberlain 1961).

D. sayi was introduced into several localities of the northeastern Atlantic coast, southwestern Britain (Ingle 1980, Clark 1986), as well as more recently to the French and Dutch coast of the North Sea (Vaz *et al*. 2007). In the Mediterranean Sea, *D. sayi* has been collected from the Venice, Marano and Varano lagoons, as well as in the Po River Delta (western Adriatic Sea) (Froglia and Speranza 1993, Mizzan 1995, Florio *et al.* 2008) and more recently in the Black Sea (Micu *et al*. 2010). It was first reported in Venice Lagoon (Froglia and Speranza 1993) in 1992, but it must have been in the lagoon since the 1980s (Occhipinti Ambrogi 2000). Nowadays, it is the most common crab in this lagoon, exceeding in abundance the native species *Carcinus aestuarii* and *Pilumnus hirtellus* forma *aestuarii* (see Mizzan 1995, Schubart pers. observ. 2006).

In the present paper, the presence of *Dyspanopeus sayi* is documented from Alfacs Bay (Ebro Delta, Tarragona, Spain). This is the first record of the species from the western Mediterranean (compare with Galil *et al*. 2002). In addition, mitochondrial DNA of three individuals of this population was compared with the DNA from two conspecifics from Venice Lagoon and with the one from selected individuals from the native range of this species. The morphology of the first zoeal stage was described in detail and compared with previous descriptions of this species.

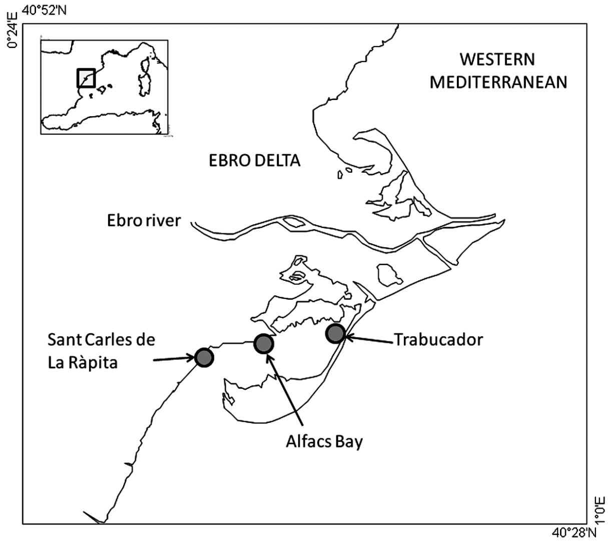

FIG. 1. – Location of the reported records of the exotic crab *Dyspanopeus sayi* in the Ebro Delta (western Mediterranean).

MATERIALS AND METHODS

Adult specimens of *Dyspanopeus sayi* were collected by hand and small beam trawls (see Fusté 1988) in Alfacs Bay, Ebro Delta (40°40' N; 0°40'E), located on the northeast Spanish Mediterranean coast (Catalonia: Tarragona) (Fig. 1) in November 2005, September 2006, and August 2010 (Table 1). Sampling depth ranged from 0.5 to 1.5 m. The samples from 2005 and 2006 were collected by hand (partly snorkelling) from pillars covered in green algae, either in the port of Sant Carles de la Ràpita or at the landward edge of the sandy spit El Trabucador. Specimens from 2010 were collected by beam trawls from sandy-muddy bottoms of Alfacs Bay covered by the seagrass *Cymodocea nodosa* and the alga *Caulerpa prolifera* (see Pérez and Camp 1986). Alfacs Bay is a shallow semi-enclosed estuary (3 m mean depth) at the south side of the Ebro River Delta complex, from which it receives freshwater from March/April to October/November, through discharge channels that flow out onto its northern shelf (Camp and Delgado 1987, Solé *et al.* 2009). The bay is separated from the Mediterranean

TABLE 1. – Specimens of *Dyspanopeus sayi* (Smith, 1869) collected from the Ebro Delta.

Collection locality	specimens	CW (mm)	CL (mm)	Date	Collectors
El Trabucador	♀	14.7	12.3	8.Nov.2005	CD Schubart, F Gmeiner and P Abelló
El Trabucador	♂	12.1	9.4	8.Sept.2006	CD Schubart, S Reuschel and L Ragionieri
Sant Carles de la Ràpita, harbour	ov.♀	12.8	10.5	9.Sept.2006	CD Schubart, S Reuschel and L Ragionieri
Alfacs Bay	♀	17.4	13.6	9. Aug. 2010	G Guerao
Alfacs Bay	ov.♀	15.7	12.4	24.Aug.2010	G Guerao
Alfacs Bay	♂	26.3	19.1	24.Aug.2010	G Guerao
Alfacs Bay	♂	20.5	15.4	24.Aug. 2010	G Guerao
Alfacs Bay	♂	19.1	13.9	24.Aug.20 10	G Guerao
Alfacs Bay	♂	22.1	15.9	09. Aug.2010	G Guerao
Alfacs Bay	♂	22.9	17.1	09. Aug.2010	G Guerao

Table 2. – Origin of specimens of *Dyspanopeus sayi* (Smith, 1869) used for genetic analyses and comparison of 658 basepairs of the mitochondrial Cox1 gene. Specimens from Canada from Radulovici *et al*. (2009) (RMNH: Naturalis Museum, Leiden; SMF: Senckenberg Museum und Forschungsinstitut, Frankfurt; ULLZ: University of Louisiana at Lafayette Zoological Collection, Lafayette; USNM: National Museum of Natural History of the Smithsonian Institution, Washington DC).

Collection Locality and Date	voucher #	accession #
Canada (Prince Edward Island): 46.052N 63.039W, 2. Aug. 2008	L228AR1-02	FJ581617
Canada (New Brunswick): St. Lawrence Bay: 46.516N 64.684W, 5. Aug. 2007	L183AR1-01	FJ581619
Canada (New Brunswick): St. Lawrence Bay: 46.224 N 64.553 W, 24. July 2007	L154AR1-06	FJ581619
USA (Florida): Fort Pierce; 18. March 1998	ULLZ 3752	FR869685
USA (Massachusetts): Boston: Watertown; 18. June 2006 (2 individuals)	USNM 1154253	FR869687
Spain: Ebro Delta: El Trabucador; 8. Nov. 2005: 40°37,712'N-0°44,470'W	RMNH-D.53427	FR869685
Spain: Ebro Delta: El Trabucador; 8. Sept. 2006: 40°37,712'N-0°44,470'W	SMF-38945	FR869684
Spain: Ebro Delta: St. Carles de la Ràpita; 9. Sept. 2006	SMF-38944	FR869686
Italia (Veneto): Venice Lagoon: Fusina; 11. Aug. 2006 (2 individuals)	USNM 1154252	FR869688

Sea by a 5 km long, 300 m wide sandbar that forms a 2.5 km wide embayment (Camp 1994). The habitat mostly consists of sandy bottoms and seagrass meadows. Crab samples were measured and conserved in 70-95% ethanol. Collected individuals were identified as *Dyspanopeus sayi* in accordance with Williams (1984) and Martin and Abele (1986). Specimens were deposited at the Biological Collections of Reference of the Institut de Ciències del Mar (CSIC) in Barcelona, under the accession code ICMD_20110201_01 and at the Naturalis Museum, Leiden; Senckenberg Museum und Forschungsinstitut, Frankfurt; University of Louisiana at Lafayette Zoological Collection, Lafayette; National Museum of Natural History of the Smithsonian Institution, Washington DC (see Table 2 for collection numbers).

From a total of eight individuals (see Table 2 for localities) DNA was extracted from the muscle tissue of a walking leg and DNA isolation was performed with a modified Puregene method from Gentra Systems. DNA pellets were resuspended in 20 µl TE buffer and the concentration was ascertained on agarose gels. From the corresponding dilutions of the DNA solution, 1µl was used for polymerase chain reactions. 658 basepairs of the mitochondrial cytochrome subunit 1 (Cox1) region were amplified with the primer combination COL6b (ACA AAT CAT AAA GAT ATY GG) and COH6 (TAD ACT TCD GGR TGD CCA AAR AAY CA) (see Schubart and Huber 2006) in PCR with a standard 25µl reaction containing 2.5µl of 10x buffer, 2.5µl of 1.25 mM dNTPs, 0.5µl of both primers (20mM), 2µl of 25mM MgCl2, 1µl of 0.5 U/µl TAQ, 15µl of double-distilled water, and 1µl target DNA. 40 cycles were run at an annealing temperature of 48°C. PCR products were cleaned using SureClean (Bioline) and sequenced with an ABI-PRISM 310 (Applied Biosystems, Carlsbad CA). Sequences were aligned by eye (no indels) together with three sequences from Genbank originating from conspecific individuals from the Gulf of St. Lawrence, Canada (FJ581617-FJ581619, Radulovici *et al*. 2009). The alignment was converted into a nexus file to construct a statistical parsimony network as implemented in the TCS software package version 1.21 (Clement *et al*. 2000). The corresponding network was then redrawn by hand.

One captured ovigerous female was kept in an aquarium (40×20×15 cm) containing well-aerated, filtered seawater at a salinity of 34 and temperature of 18±1°C. The larvae hatched on the following day and were preserved in 70% ethanol for morphological and morphometric studies. An Olympus BH-2 microscope was used to observe the setal formula of the appendages. Measurements of 20 individuals were taken with a Nikon SMZ800 stereo microscope equipped with an image analysing system (AnalySIS, SIS, Münster, Germany). The following measurements were taken: distance from the tip of the rostral spine to the tip of the dorsal spine (RDL); carapace length between eyes (base of the rostrum) to the posterolateral carapace margin (CL); carapace width as the distance between the tips of lateral spines (CW); rostral spine length, from base of eye to tip of rostral spine (RL); antenna length, from base of eye to tip of spinous process (AL). A total of 20 first zoeae was deposited in the Biological Collections of Reference of the Institut de Ciències del Mar (CSIC) in Barcelona under accession code ICMD_20110201_02.

RESULTS

Dyspanopeus sayi (Fig. 2) was identified in samples from shallow areas with a total number of 14 specimens including two ovigerous females (Table 1). Comparison of the DNA of the mitochondrial gene Cox1 of three individuals from the Ebro Delta with three sequences from St. Lawrence Bay (New Brunswick, Canada), two from Boston (Massachusetts, USA), one from Fort Pierce (Florida, USA) and two from Venice Lagoon (Italy) confirmed the species identity and gave the first indications of haplotype richness in the native as well as in the introduced populations (Fig. 3). While three animals from New Brunswick were genetically identical, those from Boston, Venice and the Ebro Delta showed distinct haplotypes between the two or three individuals sampled.

Larvae hatched at night from a single female (Fig. 4). No larva reached the second zoeal stage. Measurements of zoeal morphology and setal formulae of cephalothoracic appendages are listed in Table 3. The first zoea has the following main features: 1) Carapace

Fig. 2. – *Dyspanopeus sayi*. Adult specimen from Alfacs Bay (male; ICMD_20110201_01). Scale bar 10 mm.

with rostral, lateral and dorsal spines; length of rostral spine 1.5 times carapace length and similar in length to dorsal spine. 2) Antennal protopodal process without spinulation, longer than rostral spine; exopod minute, with one terminal seta. 3) Pleon with five somites; somites 2 and 3 with one pair of dorsolateral processes; somites 3-5 with posterolateral similar-sized processes; somites 2-5 each with one pair of posterodorsal setae. 4) Telson with long non-spinulated fork; with one dorsomedian spine on each furcal arm and three pairs of stout spinulate setae on posterior margin.

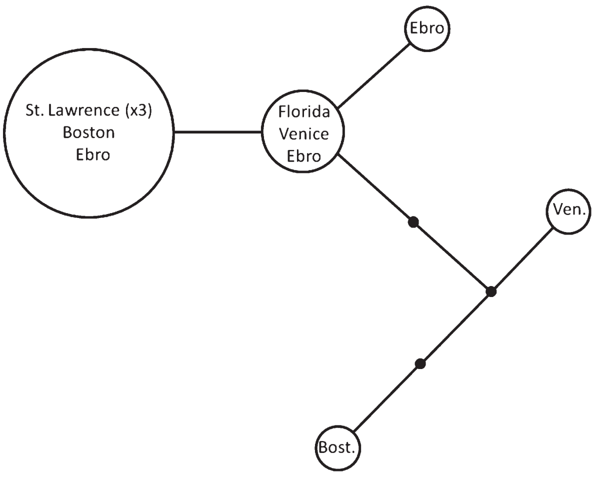

Fig. 3. – Haplotype network of eleven specimens of *Dyspanopeus sayi* from introduced Mediterranean as well as from native populations. The network is based on 658 basepairs of the Cox1 mtDNA. Population localities are written within haplotypes (Ven., Venice Lagoon; Bost., Boston).

DISCUSSION

The carapace widths (CW) of individuals captured in Alfacs Bay (males 12.1-26.3 mm, N=6; females 12.8-17.4 mm, N=4) are slightly smaller than those reported for the Black Sea population (15.4-28.8 mm for males and 12.0-19.3 mm for females respectively, Micu *et al*. 2010). In its native range *Dyspanopeus sayi* can attain a maximum size of 30 mm CW (Williams 1984, Strieb *et al*. 1995).

Two ovigerous females were collected, one in September 2006 (CW 12.8 mm) and one in August 2010 (CW 15.7 mm), which agrees with the reproductive seasonality in its native habitat: Dittel and Epifanio (1982) collected larvae of *D. sayi* from June to October in Delaware Bay. In the Adriatic and Black Sea, ovigerous females have been observed in September and from September to October respectively (Mizzan 1995, Micu *et al*. 2010).

The meristic and morphometric characteristics of the first zoeal stage of *Dyspanopeus sayi* are shown in Table 3. The morphology of the larvae agrees well with

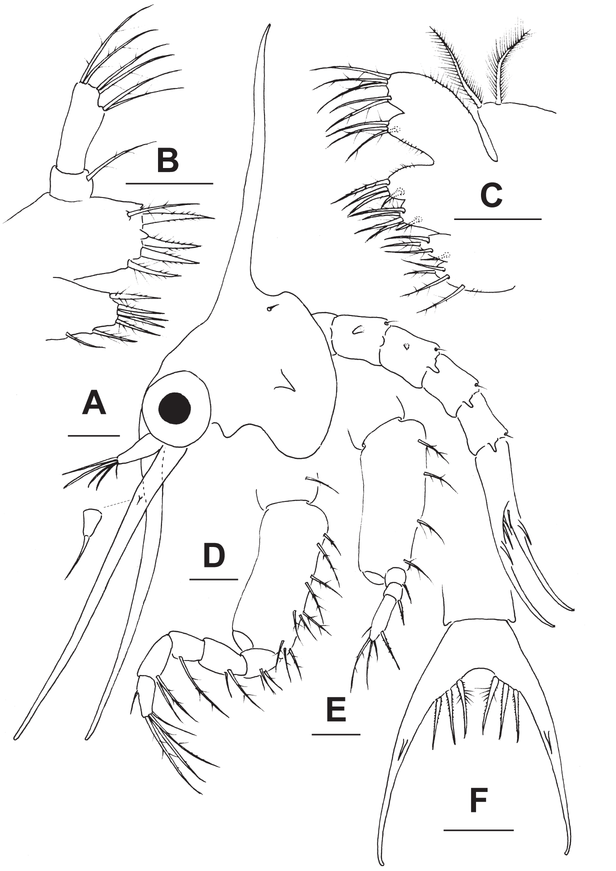

Fig. 4. – *Dyspanopeus sayi.* First zoea. Lateral view (A); maxillule (B); maxilla, endites and endopod (C); first maxilliped, exopod omitted (D); second maxilliped, exopod omitted (E); Telson, dorsal view (F). Scale bar of A and F: 100 µm; of B-E: 50 µm.

previous descriptions of the larval morphology from North American populations (Chamberlain 1961, Clark 2007). However, measurements cannot be compared, except for the rostro-dorsal length (RDL). The larvae of the Ebro Delta have clearly larger RDL values than the ones measured by Chamberlain (1961). The description of Clark (2007) does not provide biometric information in the text. However, the figures show shorter dorsal and rostral spines than those of the present description, which therefore suggests a smaller RDL. However, more biometric studies are necessary to reach conclusions about differences in the size of the Mediterranean larvae.

D. sayi has a planktonic larval development with four zoeal stages plus megalopa (Chamberlain 1961). The larval phase constitutes the dispersive stage, and is thus the crucial stage for invading crustacean species with extended development in order to establish themselves and persist in new locations as well as extend the range of new populations. Nevertheless, it is unlikely, if not impossible, that *Dyspanopeus sayi* was introduced naturally from North America or Britain into the western Mediterranean due to their planktonic larval duration and the present pattern of oceanographic currents and geographic barriers. Also the Italian Peninsula constitutes an important natural barrier which would largely restrict gene flow from the Adriatic to the western Mediterranean. Adult *D. sayi* do not migrate seasonally between the coast and deeper waters; the movements of the adults are local (Micu *et al*. 2010). We therefore propose a new human-mediated introduction of this species into the Ebro Delta, unless other, geographically intermediate populations are discovered.

Table 3. – *Dyspanopeus sayi* (Smith, 1869). Morphological and biometric characteristics of first zoea. Abbreviations: a, aesthetascs, AL, antenna length (protopod process); CL, carapace length; cox, coxa; mxpd, maxilliped; pd, posterodorsal; RDL, rostrodorsal length; RL, rostral spine length; s, setae; CW, carapace width; * described from figure.

Feature	Present study W Mediterranean	Chamberlain (1961) Chesapeake (E Atlantic)	Clark (2007) Florida (E Atlantic)
RDL (µm)	1863.5±12.4	1200	-
CL (µm)	514.4±31.9	-	-
CW (µm)	612.5±31.5	-	-
RL (µm)	786.0±12.2	-	-
AL (µm)	832.3±50.0	-	-
Carapace (s)	2pd	0	2pd
Antennula (a+s)	4+1	3-4	4+1
Maxillule			
coxal end (s)	7	6	7
basial end (s)	5	5	5
endopod (s)	1+6	1+6	1+6
Maxilla			
coxal end (s)	4+4	5-8	4+4
basial end (s)	5+4	5-9	5+4
endopod (s)	3+5	7-8	3+5
First maxilliped			
coxa (s)	1	1	1*
basis (s)	2+2+3+3	2+2+3+3	2+2+3+3
endopod (s)	3,2,1,2,5	2-3,2,1,1-2,4-5	3,2,1,2,5
exopod (s)	4	4	4
Second maxilliped			
coxa (s)	0	0	0
basis (s)	4	4	4
endopod (s)	1,1,5	1,1,4-5	1,1,5
exopod (s)	4	4	4

The genetic results of four different haplotypes found in the five analyzed individuals from introduced populations (two from Venice Lagoon and three from Ebro Delta, one of which is shared) argue against colonization events based on single female lineages in both populations and suggest that the European populations do not have strong genetic bottlenecks. This has also been shown for the second introduced panopeid crab in Europe, *Rhithropanopeus harrisii* (see Projecto-Garcia *et al*. 2010).

Commercial and non-commercial vessels are both important vectors for secondary introduction and dispersal of alien species beyond their primary location of introduction (Cannicci *et al*. 2006). Studies show that 188 metazoan species have been introduced into the Mediterranean by vessels and that the number is steadily rising. Secondary dispersion by vessels within the Mediterranean Sea is also an important issue (IUCN 2009). Decapod crustaceans are often introduced in connection with commercial maritime traffic, since their larvae can survive long periods in ballast water (Occhipinti Ambrogi 2000). Movements and exchanges of aquaculture products (i.e. bivalve seed production, commercialization of live bivalve and crustaceans) may also be a source of introduction of non-native species.

Each human-mediated introduction raises the question of the potential impact to be expected from this new member in the biological community. Predation by non-native crabs is thought to be the cause of dramatic declines in the number of clams *Mya arenaria* in northern New England and southeastern Canada (Cohen *et al*. 1995). Predation by a panopeid mud crab on the American oyster *Crassostrea virginica* (see Bisker and Castagna 1987) and the hard clam *Mercenaria mercenaria* (see Whetstone and Eversole 1981) received considerable attention due to the economic implications for commercial harvests. *Dyspanopeus sayi* is a molluscivorous crab, its main prey organisms being bivalve molluscs and barnacles. Its predator activities take place at dusk or in darkness. It uses its major chela to break open the shell of its prey (Mistri 2004). In the Adriatic Sea, *D. sayi* has exterminated prey species like *Mytilus galloprovincialis*, *Mytilaster lineatus*, *Ostrea edulis* and *Crassostrea gigas* in a very small locally restricted area (Mizzan 1998). Alfacs Bay is very important for the economy of the region due to its fish and shellfish farming and aquaculture. The mollusc species of commercial value of this area are *Mytilus galloprovincialis*, *Crassostrea gigas, Ruditapes decussatus* and *R. philippinarum* (see Ramón *et al*. 2005). The most abundant epibenthic predator is *Carcinus aestuarii* (see Fusté 1988). This carcinid crab is an important predator that may control the local abundance and distribution of populations of its benthic prey (Richards *et al*. 1999). However, in the Ebro Delta, the predatory behaviour of *C. aestuarii*, like many other aspects of its biology, is currently unknown. Thus, biological and ecological studies are necessary as soon as possible in order to assess the real impact that *Dyspanopeus sayi* can have on the Ebro Delta system.

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